Development of an Expert System Based on the Systematic Approach to Tropical Cyclone Track Forecasting

Lester E. Carr III
Department of Meteorology, MR/Cr
Naval Postgraduate School
589 Dyer Rd., Room 254, Monterey, CA 93943-5114
E-mail: carrle@nps.navy.mil
Telephone: (408) 656-2374
FAX: (408) 656-3061
Award # N0001498WR30011
http://heron.met

LONG-TERM GOALS

The long-term goals of this project are to improve the quantitative accuracy and interpretative utility of official tropical cyclone (TC) track forecasts by enabling forecasters to successfully recognize and skillfully compensate for periods when numerical TC track forecast models are likely to be making highly erroneous track forecasts. The conceptual methodology for accomplishing these goals is the Systematic Approach to Tropical Cyclone Track Forecasting (hereafter Systematic Approach) conceived by Carr and Elsberry (1994). This particular project is also being pursued in collaboration with R. L. Elsberry.

OBJECTIVES

The specific objectives of this project are to:

(i) develop a prototype expert system based on the Systematic Approach; and
(ii) demonstrate the feasibility of such an expert system for improving the accuracy and meteorological utility of official tropical cyclone track forecasts.

It is emphasized that the purpose of the expert system is not to replace the human forecaster, but to proactively lead the forecaster through a methodical process of numerical guidance evaluation and forecast formulation that produces consistently skillful official track forecasts.

APPROACH

Figure 1 shows the procedural framework of the Systematic Approach, including the principal tasks that must be accomplished in each phase. The basic approach that is being followed to create a Systematic Approach expert system is to develop a series of inter-linked software modules that assist the forecaster to accomplish each task. The formulation of an accurate TC forecast represents a highly

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE **Development of an Expert System Based on the Systematic Approach to Tropical Cyclone Track Forecasting**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Department of Meteorology,Monterey,CA,93943-5502**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

SYSTEMATIC APPROACH FRAMEWORK

Phase I: Numerical Guidance Evaluation
Phase IA: Classify Actual Meteorological Situation
Task 1: Classify TC Structure
Task 2: Classify Environment Structure/Transitions
Phase IB: Classify Model-depicted Meteorological Situation
Task 1: Classify TC Structure
Task 2: Classify Environment Structure
Task 3: Assess Numerical Guidance Accuracy
Phase II: Objective Technique Evaluation
Task 1: Identify Track Guidance Groups
Task 2: Select Guidance Group for Official Forecast
Phase III: Official Track Forecast Formulation
Task 1: Construct Primary/Alternate Envelopes
Task 2: Construct Official Track Forecast
Task 3: Assign Confidence/Alternate Scenario

Figure 1. Listing of the three phases that comprise the Systematic Approach procedural framework, and the major tasks that must be accomplished in each phase.

complex information management problem that poses challenges with regard to timely *access*, effective *display*, and informed *interpretation* of various information resources available to the forecaster. In developing the expert system, modules careful consideration is given to such things as:

(i) identification of the key information (e.g., numerical fields, imagery, data, etc.) that the forecaster must have access to either manually or with objective assistance to accomplish each step of the Systematic Approach process;
(ii) development of graphical user interfaces that lets the forecaster access and display the information in the form needed; and
(iii) development and application of knowledge bases and algorithms to assist the forecaster to interpret correctly the displayed information, particularly with regard to successful assessment of the accuracy of the available numerical model forecasts of TC motion.

Other considerations that affect how the expert system modules are developed include:

(i) Varying degrees of proactivity depending on the nature and difficulty of each task being accomplished. The idea here is establish an effective division of labor wherein the forecaster performs tasks (with machine assistance) that humans do well (e.g., such as pattern recognition), and the machine is programmed to perform tasks (with human assistance) that machines do well (e.g., display and manipulation of model fields).
(ii) Flexible design so that modules may be separately tested, revised, and re-tested. Flexibility is essential because the testing will reveal possibilities/needs for modification such as increased or reduced objective input to the forecaster.
(iii) A *HELP* function, in which a user can stop the decision process and review that aspect of the knowledge base relevant to accomplishing a particular task.

From the inception of the Systematic Approach concept, forecaster interaction and feedback have been viewed as an essential requirement for efficiently developing a product that is capable of meeting the needs of the operational forecaster. Thus, as certain key components of the prototype expert system are developed, they will periodically be provided to the forecasters at the Joint Typhoon Warning Center (JTWC) for informal evaluation and feedback to the researchers.

WORK COMPLETED

The expert system software module for Phase IA of the Systematic Approach, which assists the forecaster in classifying the actual meteorological situation (Fig. 1), was developed in the previous fiscal year. A key component of this module is an algorithm that alerts the forecaster to the possible presence of several modes of binary TC interaction using the results of Carr and Elsberry (1998). The work plan for this year was to complete development of the software module for Phase 1B, which assists the forecaster in classifying the model-depicted meteorological situation (Fig. 1), and includes an assignment of expected accuracy of the TC track forecasts made by the numerical TC track forecast model(s) available to the forecaster. As described in the next section, significant progress was made in creating the model field and forecast track display functionality required to accomplish the tasks of Phase 1B, and in developing a Model Traits knowledge base for Navy Global Atmospheric Prediction System (NOGAPS) and Geophysical Fluid Dynamics Laboratory—Navy (GFDN) models from which algorithms may be developed to alert the forecaster to the existence of erroneous forecasts by one or both models. Due to the unique and sophisticated nature of the required information display functionality, and the 0.75 man-year required to develop the foundation of a model traits knowledge base for NOGAPS and GFDN, a portion of FY 99 will be required to complete the software module for Phase 1B of the expert system. As stated in the work plan, some work has begun on developing display functionality to accomplish the tasks in Phases II and III of the Systematic Approach procedural framework (Fig. 1).

RESULTS

A pivotal accomplishment this year was a detailed analysis of the 326 NOGAPS and 287 GFDN forecasts of TC tracks in the western North Pacific in 1997. Particular emphasis was given to the 108 NOGAPS and 99 GFDN forecasts that had a 72-h forecast track error (FTE) of greater than 300 n mi, and thus were considered to be highly erroneous. For each forecast with a FTE greater than 300 n mi, a subjective evaluation of the model fields was made to determine if a plausible physical mechanism could be identified to account for the large FTE using the Systematic Approach Meteorological Knowledge Base for the western North Pacific (Carr et al. 1997).

The results of the NOGAPS and GFDN track error evaluations are summarized in Table 1. Erroneous cyclone interactions (first three rows) were by far the most frequent cause of poor NOGAPS and GFDN 72-h forecasts, and accounted for 53 (49%) and 39 (39%), respectively. Direct Cyclone Interaction was remarkably prevalent, and degraded more model forecasts than any other single phenomenon by a better than 2-to-1 margin for both NOGAPS and GFDN, and it occurred during 19 separate periods involving 16 TCs in the western North Pacific during 1997. By contrast, real Direct TC Interaction actually occurred only twice in 1997.

Meteorological phenomenon Responsible for 72-h forecast Track errors greater than 300 n mi	Number of Forecasts NOGAPS	GFDN
Direct Cyclone Interaction	37-0	30-0
Indirect Cyclone Interaction	13-0	6-2
Semidirect Cyclone Interaction	3-0	1-0
Ridge Modification by TC	11-0	14-0
Reverse Trough Formation	9-0	4-0
Baroclinic Development	8-10	11-1
Response to Vertical Wind Shear	9-0	1-5
Subtropical Ridge Modulation	4	2
Midlatitude Westerlies	0-0	3-0
Not discernable	4	12
Fields not available	0	7
Total	108	99

Table 1. Number of forecasts for which various meteorological phenomena were responsible for large (>300 n mi) 72-h forecast track errors (FTEs) in NOGAPS and GFDN. When two numbers are shown, the first (second) number indicates that phenomenon occurred in the model to an excessive (insufficient) degree, except the poor model predictions of Subtropical Ridge Modulation were simply characterized as erroneous.

Only four (4%) NOGAPS and 12 (12%) GFDN forecasts with large 72-h errors were considered to have no discernible physical explanation. It is noteworthy that most of the unexplained forecasts had FTEs less than 400 n mi, and only one had an FTE greater than 500 n mi. In other words, a discernable physical explanation could be provided for virtually all of the forecasts with very large FTEs. Since being able to readily discern a plausible reason for an erroneous track forecast is a necessary (but not sufficient) condition for anticipating such errors in an operational setting, this is considered to be a very encouraging result. This result is also an important step toward accomplishing the second specific objective of this project, which is to demonstrate the feasibility of an expert system to improve TC track forecasts.

Each of the meteorological phenomena in the first seven rows of Table 1 are in Systematic Approach Meteorological Knowledge Base considered to be TC-Environment Transformations, in which the circulation of the TC interacts significantly with the surrounding environment. By contrast, the phenomenon in the next two rows are viewed as large-scale processes to which the TC is a comparatively passive respondent. Thus, a very important finding is that the vast majority of highly erroneous NOGAPS (90%) and GFDN (76%) tracks forecasts were attributed primarily to misrepresentations of phenomena that depend sensitively on the fidelity with which the structure of the TC is represented in the model. Furthermore, in the first seven rows of Table 1, it was usually *excessive* interaction of the TC with the environment that was the cause for the poor forecast. The only two significant exceptions were a roughly equal likelihood of either excessive or insufficient Baroclinic Development in NOGAPS, and a clear tendency for insufficient Response to Vertical Wind Shear in GFDN.

During the analysis process that resulted in Table 1, it was necessary to visually analyze and compare hundreds of NOGAPS and GFDN TC forecast tracks and thousands of model fields. As a result, valuable insight was gained into the kind of track and field display capabilities that should be incorporated into the Systematic Approach expert system to facilitate successful accomplishment of the tasks of Phase 1B (Fig.

2). Accordingly, the field display functionality of the expert system how includes the ability to do synchronized display and animation of fields from one model at two levels, two models at one level, and two different runs of the same model at the same level (to check temporal continuity). Similarly, the expert system can display many TC forecast model tracks for one time, or several consecutive track forecasts by one model. In addition, track displays and field displays appear together on the same screen to facilitate comparison and analysis. Finally, an objectively-determined list of phenomena that may account for large differences between model forecasts will also appear on the same screen to assist the forecaster in discerning which model(s) are likely to be providing degraded forecast tracks. Peak et al. (1999) provides an illustration of the above aspects of information display and analysis functionality being designed into the expert system.

IMPACT/APPLICATIONS

These findings have important ramifications for operational TC forecasting and numerical TC forecast model development. For the forecaster, it means that particular attention should be paid to evaluating the numerical TC model forecasts for indications of excessive interaction with the environment. For the numerical modeler, it means that if continued improvements are to be achieved in the numerical prediction of the tracks of western North Pacific TCs, then significant effort must be directed toward achieving improved (i.e., usually less vigorous) model representations of TC structure and interaction with the environment (particularly with other cyclones). Preliminary documentation of the analysis summarized above appears in Schnabel (1998) and Carr et al. (1999), and a more complete treatment in the form of a NPS technical report is in preparation. In particular, the NPS technical report includes the characteristic biases and track patterns that tend to be associated with each of the error-producing phenomena shown in Table 1. These data are presently being analyzed and will be used to formulate objective algorithms that can alert the forecaster to the possibility of an erroneous forecast based on the shape of the forecast track and its relationship to other models forecasts.

RELATED PROJECTS

This project is a follow-on to, and utilizes the results of, the project entitled SYSTEMATIC APPROACH TO TROPICAL CYCLONE TRACK FORECASTING by Lester E. Carr III and collaborators, which appeared in the FY97 annual report.

REFERENCES

Carr, L. E., III, and R. L. Elsberry, 1994: A systematic and integrated approach to tropical cyclone track forecasting. Part I. Approach overview and description of meteorological basis. Tech. Rep. NPS-MR-94-002, Naval Postgraduate School, Monterey, CA 93943-5114, 273 pp.

Carr, L. E., III, R. L. Elsberry, and M. A. Boothe, 1997: Condensed and updated version of the systematic approach meteorological knowledge base--Western North Pacific. Tech. Rep. NPS-MR-98-002, Naval Postgraduate School, Monterey, CA 93943-5114, 169 pp.

Carr, L. E., III, and R. L. Elsberry, 1998: Objective diagnosis of binary tropical cyclone interactions for the western North Pacific basin. *Mon. Wea. Rev., 126, 1734-1740.*

Schnabel, R. G., 1998: A comparison of the NOGAPS and GFDN track prediction models during the 1997 western North Pacific typhoon season. M. S. Thesis, Naval Postgraduate School, Monterey, CA 93943, 124 pp.

Carr, L. E., III, R. G. Schnabel, and R. L. Elsberry, 1999: Systematic approach to tropical cyclone track forecasting-2: Analysis of large track forecast errors by NOGAPS and GFDN in the western North Pacific during 1997. Preprints, *23rd Conf. on Hurricane Tropical Meteorology*, Dallas, TX, Amer. Meteor. Soc. (accepted)

Peak, J. E., L. E. Carr, III, and R. L. Elsberry, 1999: Systematic approach to tropical cyclone track forecasting-3: Development of a tropical cyclone track forecasting expert system. Preprints, *23rd Conf. on Hurricane Tropical Meteorology*, Dallas, TX, Amer. Meteor. Soc. (accepted)

PUBLICATIONS

Carr, L. E., III, and R. L. Elsberry, 1998: Objective diagnosis of binary tropical cyclone interactions for the western North Pacific basin. *Mon. Wea. Rev., 126,* 1734-1740.

Carr, L. E., III, R. G. Schnabel, and R. L. Elsberry, 1999: Systematic approach to tropical cyclone track forecasting-2: Analysis of large track forecast errors by NOGAPS and GFDN in the western North Pacific during 1997. Preprints, *23rd Conf. on Hurricane Tropical Meteorology*, Dallas, TX, Amer. Meteor. Soc. (accepted)

Schnabel, R. G., 1998: A comparison of the NOGAPS and GFDN track prediction models during the 1997 western North Pacific typhoon season. M. S. Thesis, Naval Postgraduate School, Monterey, CA 93943, 124 pp.

Peak, J. E., L. E. Carr, III, and R. L. Elsberry, 1999: Systematic approach to tropical cyclone track forecasting-3: Development of a tropical cyclone track forecasting expert system. Preprints, *23rd Conf. on Hurricane Tropical Meteorology*, Dallas, TX, Amer. Meteor. Soc. (accepted)

IN-HOUSE/OUT-OF-HOUSE RATIOS

58% / 42%